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ELECTROSTATIC-INSENSITIVE DETONATOR FOR PRECISION SYNCHRONIZATION

by

Boyd C. Taylor
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February 1971

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In many regions of the United States, enough electrostatic charge can be accumulated on the human body to initiate certain commonly used military bridgewire detonators. The design of the ARC-211 detonator has been carried forward to where it is insensitive to the highest level of electrostatic energy normally expected on the human body. Measurements of the electrostatic sensitivity of M36A1 detonators are included for comparison. Functioning times of the current model of the ARC-211 detonator are given over the voltage range from 6 to 5,000 volts. At 5,000 volts, the functioning time is 2.42 microseconds, with an estimated standard deviation of 0.045 microsecond.

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BALLISTIC RESEARCH LABORATORIES

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Terminal Ballistics Laboratory

RDT&E Project No. 1T061102A33E

ABERDEEN PROVING GROUND, MARYLAND

B A L L I S T I C   R E S E A R C H   L A B O R A T O R I E S

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February 1971

ELECTROSTATIC-INSENSITIVE DETONATOR
FOR PRECISION SYNCHRONIZATION

ABSTRACT

In many regions of the United States, enough electrostatic charge can be accumulated on the human body to initiate certain commonly used military bridgewire detonators. The design of the ARC-211 detonator has been carried forward to where it is insensitive to the highest level of electrostatic energy normally expected on the human body. Measurements of the electrostatic sensitivity of M36A1 detonators are included for comparison. Functioning times of the current model of the ARC-211 detonator are given over the voltage range from 6 to 5,000 volts. At 5,000 volts, the functioning time is 2.42 microseconds, with an estimated standard deviation of 0.045 microsecond.

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I. INTRODUCTION

By request of a user of the intitial distribution of the Atlantic Research Corporation NN-D-211 detonator (ARC-211) the sensitivity of these detonators to accidental electrostatic spark discharges was examined and the current design of the ARC-211 was developed. Since the problem of static electricity hazard to detonators is not a simple one, the investigation of this hazard was expanded to include considerable detail, only part of which is reported here.

This investigation was organized to answer two basic questions relevant to the electrostatic spark hazard to detonators. (1) What are the sources of this danger and (2) how can this danger be minimized? The answers to these questions produced by this investigation can be grouped as follows:

(1) What are the sources of the electrostatic spark hazard to detonators?
   (a) Electrostatic charge (energy) accumulated on human body.
   (b) Sensitivity of the detonator to electrostatic energy
      1) discharged across bridgewire, or
      2) discharged between bridgewire and case.

(2) How can the electrostatic hazard be minimized?
   (a) By operator following established safety procedures.
   (b) By decreasing the sensitivity of the detonator to electrostatic energy
      1) discharged across bridgewire, or
      2) discharged between bridgewire and case.

This report is concerned primarily with the solution (2)(b) above, "decreasing the sensitivity of the detonator to electrostatic energy."

In the authors' opinion, many laboratories and installations located in normally humid regions have had so little trouble from static electricity in the past that their personnel have not become familiar with the electrostatic spark sensitivity of commonly used electric detonators, and have tended to forget or neglect safety procedures to protect against this

hazard. However, operations using electro-explosive devices are now being conducted under many unusual conditions, both in the field and in the laboratory, where static accumulation is possible. Furthermore, such unusual conditions seem to be growing in number.

In addition, the use of synthetic fiber clothing is increasing, and in many cases this clothing will readily generate static electricity if it is untreated for static suppression. For instance, as shown by actual reproducible tests, if an ungrounded individual removes a plastic raincoat, he acquires sufficient electrostatic energy to immediately initiate an M36A1 bridgewire detonator. Explosive setups are becoming more complex and exotic, with considerable use of static generating plastics. Normal safety procedure requires both that the explosive operator wear conductive shoes or charge drainers and work on a conductive, grounded floor. Unless both conditions are met, static electricity can accumulate on the explosive operator. There are many situations where personnel making the explosive setup and detonator hookup can be out of physical contact with an electrical earth ground unless this requirement is kept constantly in mind.

II. RESULTS

Tests were conducted on the sensitivity to electrostatic discharges of both the original and the improved design of the ARC-211 detonator. The method of reducing the electrostatic sensitivity of the ARC-211 detonators involves using conductive paint between the metal detonator case and one of the bridgewire leads, and is described in detail. The sensitivity to electrostatic discharges both before and after this change is given. For comparison, the electrostatic sensitivity of the M36A1 detonator is also given. Finally, the functioning time of the ARC-211 detonator over the range from 6 to 5,000 volts is given to illustrate that the functioning time precision is not degraded by the technique used to reduce the electrostatic sensitivity.

A. Sensitivity of Detonators to Static Electricity

The detonators have been subjected to tests involving electrostatic discharges both from a human subject (BCT) and from an equivalent electrical circuit. A description of the tests and measurements is followed by a discussion of the results in terms of the improvement noted as a result of the electrostatic sensitivity reducing technique.

1. Tests with Static Electricity from the Human Body and from an Equivalent Circuit for Human Body. To convey some idea of the sensitivity of ARC-211 and M36A1 bridgewire type detonators to static energy stored on a human body and discharged from this body to the detonator by means of an air spark, the results in Table I are presented. For these particular experiments, shown in Figure 1, the subject was of average size and weight (5 ft 10 in. tall and 170 pounds). He was insulated from a 2 ft sq aluminum plate by 0.25 in. thick polyethylene plus leather soled shoes. The capacitance to ground of the subject, measured by a Kay-lab Micro-Miker Model 402A operating at 1 MHz, was 150 pF. Electrical contact to the subject was by means of a 1 in. by 1 1/2 in. metal plate strapped to the midforearm and connected by wire to a 1/2 in. diameter metal rod held in the hand. The subject was charged to a positive high potential by bringing the metal rod into contact with a terminal connected to the high voltage power supply through a 33 megohm resistor, voltage on this terminal was indicated by an electrostatic voltmeter. The subject was then discharged to the detonator by quickly moving the metal rod about 2 in. to another terminal connected by insulated cable to the detonator. The two cables connecting the detonator to the apparatus were 6 ft lengths of insulated core of RG58A/U coaxial cable, with the measured capacitance between cables being 50 pF. Three pulses were applied to the detonator at each voltage level until either the detonator fired or withstood three pulses of 20 kV, the maximum voltage used in these tests.

Usually in testing detonators for sensitivity to static discharges from the human body, the human body itself is not used, but instead it is

Table I

Sensitivity of Detonators to Static Electricity
from Human Subject

DETONATOR TYPE	DISCHARGE LOCATION	CHARGING VOLTAGE (kV) 5.0	7.5	10.0	12.5	15.0	17.5	20.0
ARC-211 ORIGINAL DESIGN	CASE TO BRIDGEWIRE (BW)	000	X					
		000	000	X				
		000	0X					
		000	000	X				
		000	000	X				
	ACROSS BW							000
								000
								000
								000
								000
ARC-211 CURRENT DESIGN	CASE TO BW							000
								000
								000
								000
								000
	ACROSS BW							000
								000
								000
								000
								000
M36A1	CASE TO BW	000	X					
		000	X					
		000	X					
		000	000	X				
		000	X					
	ACROSS BW	000	X					
		000	000	X				
		000	X					
		000	X					
		000	X					

Notes: 1. 0 indicates "no-fire" to single voltage pulse.
X indicates "fire" to single voltage pulse.
BW indicates bridgewire.
2. Human subject standing w/shoes on 0.25 in. thick polyethylene on 2 ft sq aluminum ground plate measured 150 pF.
3. Electrical connection between charged subject and detonator lead was by air spark to a 0.5 in. diameter rod held in hand with a wire connecting the rod to a 1.5 sq in. metal plate strapped to midforearm.
4. Capacitance between the two leads (6 ft length each) of insulated core of RG58A/U coaxial cable connecting to the detonator was 50 pF.
5. Positive pulse applied to case with BW grounded.

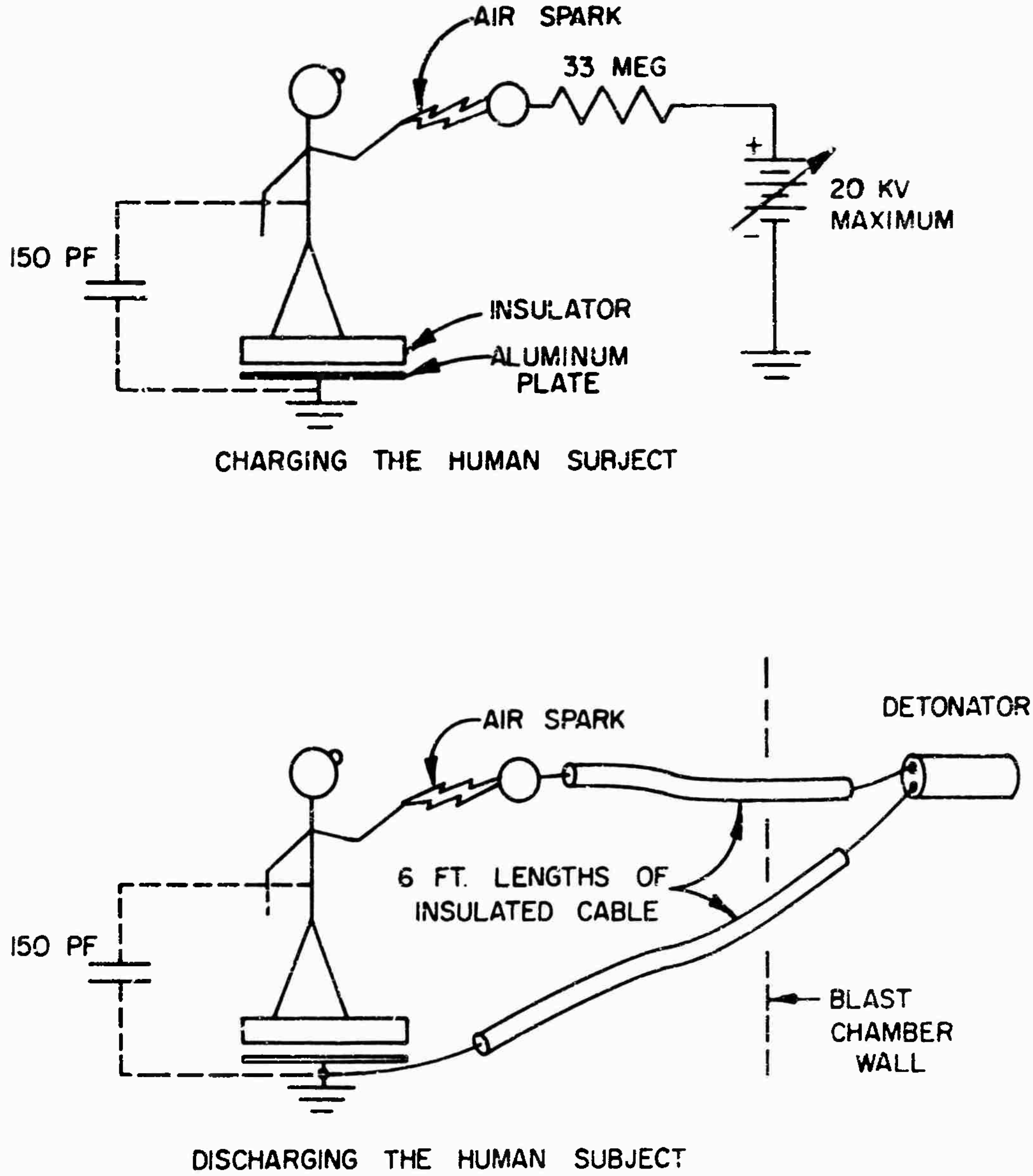

Figure 1. Detonator Tests with Static from Human Subject

approximated by an equivalent circuit consisting of a capacitor and a resistor in series. Various values for the circuit constants, as well as for the maximum voltage of the accumulated static charge, are given by different investigators. For the limited purpose of this report, the equivalent circuit consisted of a 500 pF capacitor charged to 20 kV maximum with a zero ohm series resistor. This combination was an extremely conservative one in that it delivered much more energy to a low resistance bridgewire than would an actual human body charged to the same voltage. Results obtained with this circuit are shown in Table II.

As for the problem of establishing a realistic equivalent circuit for the human body, several considerations should be mentioned. First, there is the problem of measuring the dynamic resistance of the human body for a high-voltage discharge (generally to one hand). This resistance differs greatly from the value of 5,000 ohms or so accepted for electrocardiographic recording. Second, there is the problem of specifying the resistance of the air spark which is the means by which the energy stored on the human body is switched to the detonator. Third, there is the difficulty of determining how to treat the possibility that the electrostatic energy stored on the human body might be transferred first to some intermediate object and then to the detonator. If the dynamic resistance of this intermediate object is appreciably lower than that of the human body, this process can result in delivering sufficient energy to initiate the detonator in circumstances where it could not be initiated by a direct discharge from the human body.

As noted in Table II, the human body equivalent circuit was discharged by means of a 5C22 hydrogen thyratron tube which has appreciable dynamic resistance during a short duration pulse. To further test the current design ARC-211 detonator, a 20 kV pulse was generated by discharging the human body equivalent circuit by means of a vacuum switch, and this pulse was applied between the bridgewire leads and the case. The pulse was of negative polarity and the case was grounded. A total of 30 units were tested in succession, each subjected to 3 pulses of 20 kV each, and none detonated. There have been no initiations in 100 detonators tested for

Table II

Sensitivity of Detonators to Static Electricity
from Equivalent Circuit for Human Body
(500 pF in Series with Zero Ohms)

DETONATOR TYPE	DISCHARGE LOCATION	CHARGING VOLTAGE (kV) 2.5	5.0	7.5	10.0	12.5	15.0	17.5	20.0
ARC-211 ORIGINAL DESIGN	CASE TO BRIDGEWIRE (BW)	000	X						
		000	X						
		000	X						
		000	00X						
		000	X						
	ACROSS BW		000	000	000	000	000	000	000
			000	000	000	000	000	000	000
			000	000	000	000	000	000	000
			000	000	000	000	000	X	
			000	000	000	000	000	000	000
ARC-211 CURRENT DESIGN	CASE TO BW		000	000	000	000	000	000	000
			000	000	000	000	000	000	000
			000	000	000	000	000	000	000
			000	000	000	000	000	000	000
			000	000	000	000	000	000	000
	ACROSS BW			000	000	000	000	000	000
				000	000	000	000	000	000
				000	000	000	000	000	000
				000	000	000	000	000	000
				000	000	000	000	000	000
M36A1	CASE TO BW		000	00X					
			000	0X					
			X						
		000	X						
		000	X						
	ACROSS BW		X						
			X						
			X						
			X						
			X						

Notes:
1. 0 indicates "no-fire" to single voltage pulse.
   X indicates "fire" to single voltage pulse.
   BW indicates bridgewire.
2. Pulse was generated by discharging the 500 pF capacitor through a 5C22 hydrogen thyratron switch tube.
3. Capacitance between the two leads (6 ft length each) of insulated core of RG58A/U coaxial cable connecting to the detonator was 50 pF.
4. Negative pulse was applied to case with BW grounded.

electrostatic sensitivity with the equivalent circuit at 20 kV. Therefore, there is a greater than 96 percent probability (at the 95 percent confidence level) that the current design of the ARC-211 detonator is immune to human static of 20 kV or less.

The energy stored by the 500 pF capacitor charged to 20 kV is 0.1 joule or 1,000,000 ergs. If this circuit is discharged across the detonator bridgewire by means of a vacuum switch, then most of this energy is delivered to the bridgewire and the detonator will fire. When this same circuit is discharged by a 5C22 switch tube, the energy divides between the dynamic resistance of the tube and the resistance of the bridgewire with the result that insufficient energy reaches the bridgewire to fire the detonator.

2. Discussion of Results of Tests with Static Electricity. These tests reveal the following about the sensitivity of these detonators to static from the human body and from the equivalent circuit:

(1) Sensitivity to static electricity from the human body (Table I)

(a) Case to bridgewire mode

1) The sensitivity of the original design of the ARC-211 was about equal to that of the M36A1, both being in the neighborhood of 7.5 kV, which is not a high voltage for accidental static electricity accumulation.

2) The current design of the ARC-211 successfully withstood the maximum test voltage of 20 kV.

(b) Across bridgewire mode

1) Both the original design and the current design of the ARC-211 withstood the maximum voltage of 20 kV.

2) The M36A1 was fired by static charge of 7.5 kV, which again, is not a high voltage.

(2) Sensitivity to static electricity from the human body equivalent circuit (500 pF in series with zero ohms, Table II)

(a) Case to bridgewire mode

1) Again, the original design of the ARC-211 and the

M36A1 are about equal; both fired at about 5.0 kV with this circuit.

2) The current design of the ARC-211 was not fired by the maximum test voltage of 20 kV.

(b) Across bridgewire mode

1) The ARC-211 was insensitive to static pulses across the bridgewire. The original design had one fire at 17.5 kV while four withstood 20 kV, and the current design lot of five withstood the maximum test voltage of 20 kV.

2) The M36A1 fired at 5.0 kV in this test, which is not a high voltage for accidental static electricity accumulation.

B. Current Design of ARC-211

Discussions on methods to reduce the static sensitivity of the original design of the ARC-211 detonator* resulted in two possible methods, both of which were simple and inexpensive. Subsequent tests at the Ballistic Research Laboratories (BRL) showed both methods to be effective, in that they rendered the detonator insensitive to a series of five static discharges from a 500 pF capacitor charged to 20 kV applied between the case and bridgewire. Both methods depend on establishing a conducting path between one of the bridgewire leads and the metal case, so as to limit the potential difference that can exist between these two structures during a static discharge, and hence reduce the possibility of an electric spark occurring in the interior of the detonator. Of course, the most direct method of establishing this conducting path would be a metal link from one bridgewire lead to the metal case. However, this would require a major change in the manufacturing process and increase the cost appreciably, so other methods were sought. One method is the use of a conductive epoxy applied between one bridgewire lead and the case after the detonator has

* *Private communication, Mr. Patrick Cannon, Flare Northern Division of Atlantic Research Corporation.*

been assembled and crimped. Since this conductive epoxy is difficult to apply quickly and precisely, the authors determined by test that another method using flexible conductive paint* was more suitable, Figure 2. After the conductive paint has dried, it is given a coating of insulating varnish which serves to protect it. However, the conductive paint patch remains visible through the varnish and this serves to identify the electrostatic insensitive detonators of current design.

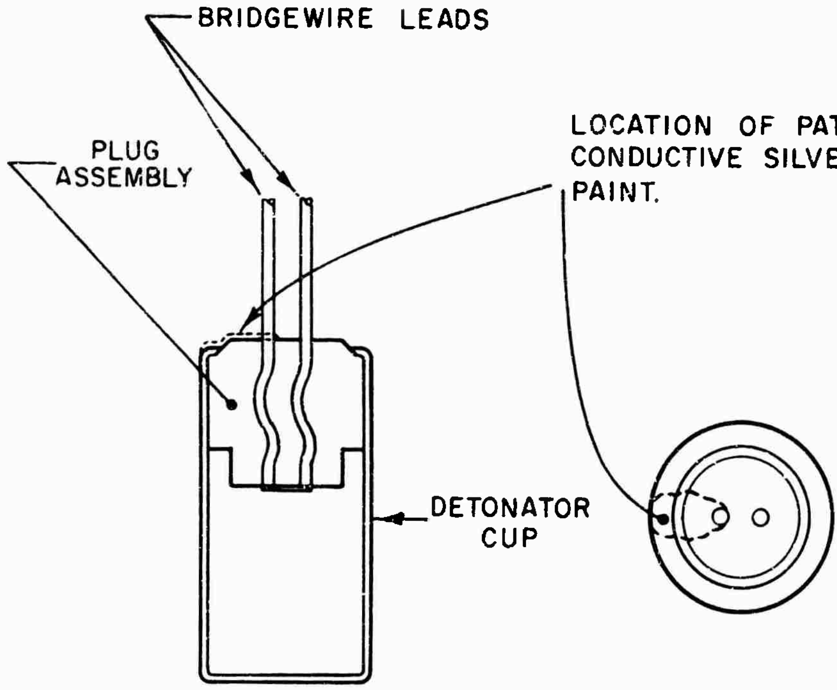

Figure 2. Detonator with Flexible Conductive Paint Patch

An interesting and useful result from these tests is that the conductive path established by the paint is fully effective in protecting the detonator even when the continuity of the path suffers small breaks. The results in Table III show that the conductive paint offered full protection whether its initial resistance was high or low. In most cases, application of five pulses from a 500 pF capacitor charged to 20 kV served to open the path, but the protection afforded by the paint was not

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**Silver Micropaint, Type SC-13, Micro-Circuits Company, New Buffalo, Michigan (possible alternatives not investigated).*

affected. In a separate test, solvent was used to remove all visible traces of the paint, but the particles which remained on the surface apparently offered a preferred path for voltage breakdown, and still served to protect the detonator against static electric discharges.

Table III. Performance of Conductive Paint in Protecting ARC-211 Detonators against Static Electricity*

Resistance of Paint (ohms) Before Test	After Test	Effect of Test on Detonator
2	open	did not fire
2	open	did not fire
10	open	did not fire
11	open	did not fire
36	0.7	did not fire
40	open	did not fire
90	open	did not fire
120	0.4	did not fire
150	open	did not fire
2300	open	did not fire

*Note: Test consisted of applying five pulses between bridgewire and case. The pulses were generated by discharging a 500 pF capacitor (charged to 20 kV) in series with zero ohms through a 5C22 hydrogen thyratron switch tube.

The effectiveness of this conductive path in protecting the detonator against a static discharge applied between case and bridgewire is also shown in Tables I and II when one compares the results for ARC-211 original design and current design, both samples being from production lots.

The primary objective of designing the electrostatic protection in the form of conductive paint rather than by modifying the metal detonator shell was to minimize the cost of this improvement. That this objective was met is borne out by the fact that this change was made midway through a production contract for 10,000 of these detonators at no increase in price. The most recent contract, for 15,000 detonators, was satisfactorily completed at a cost of $1.895 each. Thus this detonator still ranks as

inexpensive.

C. Functioning Time of Current Design of ARC-211

The functioning time of the ARC-211 detonator as it is currently manufactured is tabulated in Table IV along with the charging voltage and size of energy storage capacitor. Where the functioning time distribution exhibits relatively small dispersion, the average functioning time, estimated standard deviation, and sample size are tabulated. In other cases, only the raw data are tabulated.

Attention is called to the fact that the functioning time of this detonator is relatively insensitive to firing voltage. Lowering the voltage from 5,000 V to 500 V, a factor of 10, results in only approximately doubling the functioning time. from 2.42 to 5.58 microseconds. The detonator is useable at voltages as low as 6 V, and at this level its functioning time is approximately 500 microseconds.

Specifications require that the detonator withstand 0.5 amp DC for one minute, and survive five pulses from a 500 pF capacitor in series with zero ohms discharged by a vacuum switch. The capacitor is charged to 20 kV, and the pulses are applied between the shorted bridgewire leads and the detonator case.

Table IV. Functioning Times of ARC-211 Detonators Fired through 15 ft of RG58A/U Coaxial Cable

Voltage (volts)	Capacitance (μF)	Functioning Time (μsec)
5000	1	2.42 σ = .045 N = 30
3000	1	2.63 σ = .079 N = 10
500	1	5.58 σ = 0.37 N = 5
300	1	7.8 16.4 11.2 55.6 11.4
6	battery	470 530 510 640 520

Note: σ = estimated standard deviation
N = sample size

III. CONCLUSIONS

1. The objective of designing and manufacturing an inexpensive detonator immune to static electricity and suitable for precision synchronization has been met. Two direct tests, one using the human body and the other using a very conservative equivalent circuit for the human body (of 500 pF in series with zero ohms), have shown that the ARC-211 detonator of current design is immune to static electricity from the human body up to at least 20 kV.

2. The technique of using conductive paint to establish a path to harmlessly dissipate a static electricity discharge from the human body to an electric detonator has been developed and the value of this technique has been successfully demonstrated in production lots of the ARC-211 of current design.

3. The desirable low-voltage characteristics of the detonator have been retained, and it will function reliably down to 6 volts.

4. These investigations have revealed the complexities of establishing a realistic equivalent circuit for actual electrostatic discharges from the human body. When the very conservative equivalent circuit of 500 pF in series with zero ohms is used, the safety margin is over-designed in some cases. It is felt that consideration should be given to the problem of specifying a more realistic human body equivalent circuit and incorporating it into military specifications.